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Defining and Measuring Innovative Thinking Among Engineering Undergraduates

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Defining and Measuring Innovative Thinking Among Engineering Undergraduates

Abstract: Innovative thinking skill development among engineering undergraduates is of critical importance to the global economy. Instructional technology, when used effectively, has been shown to enhance educational environments facilitating active and engaging learning strategies such as providing access to information and collaborative exchanges focused on generating innovative solutions. Recent advancements in tablet computers, a form of instructional technology, and their impact on innovative thinking skills have been relatively unexamined. This paper provides a descriptive overview of the quasi-experimental mixed method approach utilizing a control and treatment group that is being used to explore whether effective use of instructional technology, specifically tablet technology, has an impact on the innovative thinking skills among engineering undergraduates enrolled in large lecture classes. Early results indicate that engineering undergraduates may start off with similar levels of innovative thinking skills and certain pedagogical approaches, including use of slate technology by instructors, can enhance those skills.

Innovative thinking has been defined as a "complex thinking process that is used to transform creative ideas into useful products and services[1]." In the context of educating undergraduate science, technology, engineering and math (STEM) majors, included in the definition is the assumption that an innovative individual has the skills necessary to accept change, the ability to problem-solve by applying known information to unknown situations, the ability to find unknown information and assess its value or worth, and the ability to collaborate to synergistically develop new ideas[1, 2, 3]. Innovative thinking also includes the ability to carefully select tools employed in the thinking and design process[1, 2, 3, 4].

Literature has attempted to highlight skills that innovative engineering undergraduates would demonstrate. Using TRIZ theory (e.g., a theoretical model for inventive problem solving), problem-solving methodologies, and a variety of corporate based literature as references, engineering educators suggest that students would be able to set goals for their own learning and identify when they need to seek new knowledge to solve problems. Innovative thinkers should be able to give and receive feedback on new ideas as well as possess the ability to represent those ideas visually and contextually. Students should also be able to think critically so that they can assess the value of their prior knowledge and elaborate, translate, and summarize known and new information[2, 3, 4]. Documented attempts to develop and assess these skills among engineering undergraduates have been limited to senior capstone design courses and an approach that includes additional classes or a new curriculum coupled with workshops and training for both faculty and students that introduces students to the concept of innovative thinking[2, 3, 4].

Recent literature describes how these skills can be learned if individuals are provided with the opportunity to exercise and practice thought processes associated with innovative thinking. For instance, engaging in questioning that challenges commonly known or accepted behavior, critically observing processes in order to identify new ways of doing things, networking in order to meet people with different ideas, and having the opportunity to experiment to identify new insights allow for associational thinking. The steps tied to associational thinking allow individuals to draw connections between ideas or problems from unrelated fields and generate innovative ideas[5].

Conceptual Framework

Instructional technology, when used effectively, has been shown to enhance educational environments facilitating active and engaging learning strategies. These strategies can provide opportunities for associational thinking such as providing access to information, ideas, and collaborative exchanges focused on generating innovative solutions[5]. Recent advancements in slate enabled laptop computers and smaller slate hand-held devices (e.g., Tablet PCs, iPads, HP Slate 500s), a form of instructional technology, and their impact on innovative thinking skills have been relatively unexamined.

Previous studies provide a framework to examine how instructor-led use of slate enabled technology might impact students' innovative thinking skills[6]. Structured use of instructional technology is when the instructor has embedded specific strategies into their lectures or teaching such as short lectures following by practice sessions using similar forms of technology[7], collaboration sessions within the lecture format where students communicate with one another using similar forms of technology[8], case studies[8], or use of software within the course[8]. Research has shown that structured use of instructional technology can encourage student learning behaviors that support learning[6, 8] and increase student engagement among engineering undergraduates[9]. In contrast, unstructured use allows the students to choose what they do with the instructional technology and whether they utilize features of the tablets and slates or opt to use paper, pen, or typing their notes. While the instructor might use the technology, there are no class assignments that would require students to have the technology in their class as doing so does not hinder participation[6].

This paper shares the methodology being used in a NSF funded study to examine whether instructor use of instructional technology, specifically slate enabled technology, has an impact on the innovative thinking skills among engineering undergraduates enrolled in large lecture classes and if there is an impact, what type of use by the instructor (i.e., structured use, unstructured use, or not using technology) influence that skill development. Initial findings from this exploratory study including the pre-survey and course observations are also shared.

Methodology

The overall methodology being used in this study is a mixed method approach[10]. Quantitative survey data is being paired with open-ended responses from survey data and class observations to better understand how instructor use of slate enabled technology can impact innovative thinking among engineering undergraduates in large lecture classes. This paper reports the findings from the administration of the pre-survey and semester-long observations of the different classes and is designed to explore whether differences in innovative thinking exist among students and explains how changes in those skills over the course of an academic year will be examined.

In terms of the sample, three large lecture undergraduate classes that have faculty who use tablets in conjunction with other instructional technology varying degrees or not at all were purposefully selected for participation at the start of the academic year. Previous assessment efforts identified the distinct pedagogy that each faculty member uses in their class in relation to tablet technology. One faculty makes structured use of slate technology and the students enrolled in this course are first year engineering students. The second faculty member makes unstructured use of tablet technology and the students enrolled in this Statics course are primarily second year and other upper class students. The third faculty member makes no use of tablet technology, preferring to use either an Elmo overhead presenter or notes provided via a whiteboard and dry erase marker. The third course is also a Statics course and students enrolled in the third course are also primary second year and other upper class students. Having these three different courses will allow us to compare whether different uses of tablet technology, led by the faculty member, make an impact on students' innovative thinking skills.

The methodology being used for this project will avoid a media comparison study[10]; we are not comparing the use of instructional technology versus the lack of instructional technology. Studies that resort to media comparisons have consistently shown no significant difference between groups[11]. Our research is meant to explore how active and engaging learning strategies, primarily those that use slate enabled technology and its related features, impacts students' innovative thinking skills in large lecture courses and in doing so address a gap in the literature. Previous studies have already identified active and engaging learning environments as a major factor in facilitating the development of these skills[2,3,4]. Slate enabled technology has been identified as a factor that can aid in the creation of these types of learning environments[12, 13]. It is unknown the degree to which this form of instructional technology impacts innovative thinking and what the best pedagogical approaches are when considering employment of this technology to facilitate development of these skills. In order to determine this, the project team feels that is important to examine in detail, pedagogical approaches that utilize slate enabled instructional technology in a manner that is designed to influence students' innovative thinking skills. In order to assess the impact that these approaches have on students' innovative thinking it is necessary to have a control group of students. This control group, while exposed to slate enabled instructional technology as a result of the student Tablet PC requirement, are not in a course section where the instructor is intentionally using this form of technology to develop innovative thinking skills. This design will provide us with the necessary information to create a pedagogical model that can be used to influence students' innovative thinking skills[11].

At the start of the academic year all of the 1,180 students enrolled in the participating course sections were asked to complete a survey in the fourth week of the fall semester. Two reminders were sent to students that did not complete it. In total, 192 students completed the survey. Respondents included 80 first-year students enrolled in the structured course, 42 students enrolled in the unstructured course, and 70 students enrolled in the course that did not use slate enabled instructional technology.

Items on the survey asked students to rate how frequently they engaged in certain learning behaviors associated with innovative thinking skills and to also rate their innovative thinking skills in comparison with their peers. The portion dealing with the learning behaviors is based on the Modified Strategies for Learning Questionnaire (MSLQ), a valid and reliable survey, and provides a measure of the skills identified in the literature as linked to innovating thinking. Questions asked students how often they utilize the following skills including:

knowledge acquisition (e.g., repetition of words or concepts), scaling (e.g., outlining, organizing information), elaboration (e.g., paraphrasing, summarizing), critical thinking (e.g., application of new knowledge to situations, generation of new ideas), self-initiated exploration (e.g., self-directed learning, setting goals, monitoring one's own comprehension), and peer collaboration (e.g., using a study group or friends to help learn and generate new ideas) through the creation of scales from multiple items. Our previous assessment efforts indicate that the scales indicate a moderate to acceptable degree of reliability (α< .70) based on Chronbach's alpha scores. The second set of questions that were designed to determine students' self-perceptions of innovative thinking skills in comparison to peers were based on the stages of innovation utilized by Zheng[14] which suggests that at the initial stages students should be able to identify innovative solutions while in more advanced stages students should be able to communicate innovative designs to others and begin to prototype those ideas and solutions for commercialization. Ten questions asked on a scale of Well Below Average to Well Above Average how students perceived their ability to identify innovative solutions, design innovative solutions, share those solutions with others, and integrate engineering content knowledge to generate new ideas and solutions.

One-way ANOVA was used to determine whether there are differences in frequency of students innovative thinking and also their self-reported perceptions of level of innovative thinking based on the type of instructor facilitated use of slate enabled technology (e.g., structured, unstructured, no use). Differences in innovative thinking skill frequency and level by type of instructor-led use are reported in Table 1 and Table 2.

In terms of specific innovative thinking skills, in the pre-survey students reported very few differences across groups (refer to Table1). During the initial start of the semester students' reported frequency of use of innovative thinking skills in the areas of Knowledge Acquisition, Scaling, Elaboration, Critical Thinking, Self-Initiated Exploration, Collaboration, and Entrepreneurialism are relatively similar with few significant differences between the groups of students.

TABLE 1. EARLY MEASUREMENT OF INNOVATIVE THINKING FREQUENCY

Innovative Thinking Skill	**MSLQ Related Survey Questions Used to Measure Innovative Thinking Skill** **"How often do you do the following?"**	**Structured** **M** **(n=80)**	**Unstructured** **M** **(n=42)**	**No Use** **M** **(n=70)**	**F=** ***p*=**
Knowledge Acquisition	-I make lists of important items for this course and memorize the lists.	2.90	2.98	3.39*	F=3.551 *p*=.031
Scaling	-I made simple charts, diagrams, or tables to organize course material.	3.21	2.83	2.91	F=1.659 *p*=.193

	-I asked myself questions based on my notes and other materials to be sure I understand the material being covered in my classes.	3.18	3.21	3.28	F=.152 *p*=.859
	-When I studied the readings for my courses, I outlined the material to help me organize my thoughts.	2.64	2.31	2.73	F=1.741 *p*=.178
Elaboration	-I try to apply ideas from web-based sources to other class activities such as lecture and discussion.	2.86	3.10	2.91	F=.583 *p*=.559
	-When I studied for this course, I pull together information from lecture, readings, and discussions.	3.64	4.00	4.16*	F=5.076 *p*=.007
Critical Thinking	-I often questioned things I heard or read in the course to see if I found them convincing.	2.90	2.98	3.11	F= .826 *p*=.439
	-I reread my course materials as a starting point and tried to develop my own ideas about it.	2.85	3.10	3.13	F= 1.47 *p*=.232
	-Whenever I read or heard an assertion or conclusion in class, I thought about possible alternatives.	3.25	3.29	3.14	F= .351 *p*=.705
Self-Initiated Exploration	-I tried to change the way I studied in order to fit the course requirements and the instructor's teaching style.	3.51	3.40	3.62	F=.562 *p*=.571

	-When studying for the class I tried to determine which concepts I didn't understand well.	4.05	4.19	4.12	F=.358 *p*=.700
	-When a theory, interpretation, or conclusion is presented in class I try to decide if there is good supporting evidence.	3.30	3.10	3.04	F=.1.39 *p*=.251
Collaboration	-I tried to work with other students from this class to complete the course assignments.	3.61	4.07	3.79	F=.2.27 *p*=.106
Entrepreneurialism	-I share new ideas and present new ideas to others for feedback.	3.25	3.26	3.06	F=.913 *p*=.403

Similar to what was seen in terms of frequency of innovative thinking skill use, there are few differences between groups in the results for self-perceived stages of innovative thinking.

TABLE 2. MEASUREMENT OF INNOVATIVE THINKING LEVEL

Stages of Innovation (Zheng, 2010)	**"In comparison to your peers, please rate yourself in the following areas…"**	**Structured M (n=80)**	**Unstructured M (n=42)**	**No Use M (n=70)**	**F= ; *p*=**
Creativity	Ability to identify innovative solutions	3.66	3.76	3.64	F=.353 *p*=.703
	Ability to find unknown information and assess its value or worth.	3.61	3.60	3.57	F=.038 *p*=.962
Knowledge Creation	Ability to design innovative solutions.	3.59	3.69	3.57	F=.324 *p*=.724
	Ability to apply or	3.73	3.79	3.57	F=.1.06

	integrate engineering content knowledge to generate new ideas or solutions.				*p*=.348
Innovativeness	Ability to communicate innovative designs and solutions to others, including faculty or industry representatives.	3.58	3.50	3.81	F=.2.01 *p*=.136
	Motivation to develop innovative thinking skills (e.g., skills that will allow me to identify innovative solutions and market them).	3.75	3.71	3.72	F=.033 *p*=.968
Innovation Generation	Ability to prototype innovative ideas and solutions.	3.58	3.52	3.42	F=.614 *p*=.542
	Ability to use different technologies in the innovation process.	3.56	3.55	3.57	F=.005 *p*=.995
Innovation Implementation	Ability to work with team members to design and share innovative solutions.	4.00	3.83	3.91	F=.441 *p*=.644
Diffusion	Awareness of resources on campus that will allow me to participate in innovation activities.	3.25	2.90	3.41*	F=3.181 *p*=.04

*Note: Identifies items where there were significant differences between user groups

While pre-survey results indicate similar frequency of reported use of innovative thinking skills and similar levels of self-perceived stages of innovation, bi-weekly observations of the classroom and instructor use of pedagogy designed to facilitate innovative thinking through technological applications differed markedly. Instructors selected to participate in this study deviated very little from their traditional approach to teaching and using instructional technology. For instance, the ‘No Use’ instructor provided all course content via lecture with notes handwritten on a Whiteboard that is not accompanied by a Powerpoint presentation or DyKnow software. Moreover, students in this particular course section do not bring their laptops or other devices with them into class as they are not required by the instructor. This means that the students predominately relied on hand-written notes to capture what the instructor is providing in terms of content. The ‘Unstructured Use’ faculty member primarily uses the TabletPC along with DyKnow to engage students, inking powerpoint slides and recording the lectures for later viewing. The ‘Structured Use’ faculty member uses the TabletPC along with DyKnow and frequently asks students to ink and submit panels for immediate feedback and clarification, uses polling features within the DyKnow software to gauge student feedback, and does not record or project their computer’s screen so that students must bring their own laptop if they want to view what the instructor is discussing and to participate in the class.

Discussion

Overall, results reveal that there are few differences in innovative thinking skill level when comparing the students at their initial point of entry into different classes. The observational data collected in each course in conjunction with this study shows that students appear more engaged in classes that provide a structured use format of the slate enabled technology. In order to answer the research questions posed in this study more fully a follow-up survey will be conducted among the students enrolled in each of the three courses during the final week of the spring semester to examine whether their frequency of innovative thinking skills usage changed. This post-survey will also examine the extent to which students’ perceptions of innovative thinking skill competency in comparison to peers changed. Significant differences between initial findings and those reported by students in the follow-up survey will be examined. Furthermore, changes within and between groups will be analyzed in the context of the field notes from the bi-weekly observations of the classes.

While the findings in this paper are preliminary in nature, as the follow-up survey results are analyzed, future findings from this study can be used to consider how to improve innovative thinking skills through effective pedagogical approaches. Early results from this study indicate that students may enter into their engineering courses with a similar propensity to acquire innovative thinking skills. Unless course instructors utilize pedagogical approaches that are explicitly designed to encourage those skills, the skill level may remain the same as they progress to their second year.

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